A NEW BUNCHING SCHEME FOR INCREASING THE LANSCE WNR PEAK BEAM CURRENT*

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Abstract

The LANSCE linac simultaneously provides both H- and H+ beams to several user facilities. The Weapons Neutron Research (WNR) user facility is configured to accept the H- beam with a typical pulse pattern of one linac micro-pulse every 1.8 microseconds. This pattern is produced through a combination of chopping and bunching in the 750 keV beam transport. One downside of the chopping process is that the majority of the beam produced by the ion source during each WNR macro-pulse is discarded. By applying a longitudinal bunching action immediately following the ion source, simulations have shown that some of this discarded beam can be used to increase the charge in these micro-pulses. Recently, we began an effort to develop this buncher by superimposing 16.77 MHz RF voltage on one of the HVDC electrodes in the 80 kV column adjacent to the source. This paper describes the beam dynamics simulations, design and implementation of the RF hardware and the results of tests performed with the system.

INTRODUCTION

To perform neutron time-of-flight experiments in the energy range of interest, the WNR facility at LANSCE typically employs an 800 MeV beam consisting of micropulses spaced ~1.8 μs apart. To achieve this result, a slow-wave chopper is employed in the 750 keV low-energy beam transport (LEBT) to intensity modulate the beam. The small bursts of beam are subsequently bunched at 16.77 and 201.25 MHz in the LEBT for efficient capture into the drift tube linac (DTL). To produce the desired micro-pulse pattern, the chopper effectively removes over 98% of the beam produced by the H- ion source during each WNR macropulse. By employing another buncher, some of this discarded beam could be used to increase the peak current in the WNR beam [1]. One possible location for a buncher would be in the 80 keV LEBT which is located in the Cockcroft-Walton (CW) dome. Unfortunately, there is no readily available space in the present 80 keV LEBT for a 16.77 MHz $\beta\lambda/2$ non-resonant structure. Revising and rebuilding this LEBT to accommodate the cavity would be time consuming and costly. An alternative approach that is described herein is the application of RF to the 80 kV accelerating column to bunch the beam and effectively raise the peak current within the chopper window. Also, by bunching the beam closer to the ion source, a smaller modulation would be required, thereby preserving beam quality. It was thought that this approach might be a less costly but effective way to achieve the desired result. The DC column following the ion source has four electrodes: -80 kVDC (Pierce), -68 kVDC (extractor), -32 kVDC (column) and ground. Particle tracking simulations showed that RF impressed upon the extractor electrode would result in bunched beam at the chopper. Detailed beam dynamics simulations were used to better estimate the potential gain in WNR beam current and the amount of RF voltage required to achieve this effect.

SIMULATIONS

The simulations were divided into two parts. The first evaluated the effective energy modulation impressed upon the DC beam by a given amount of RF voltage applied to the extractor electrode. The second part focused on detailed beam dynamics simulations using PARMILA [2] to evaluate the net increase in charge per bunch in the WNR micropulses.

Beam Energy Modulation

A simple single-particle model was used to estimate the net energy modulation impressed on the beam with RF voltage applied to the column electrode. In this model, with the nominal DC voltages applied to the column, a single H- ion at an initial energy of 12 keV was tracked from the extractor electrode to ground with 16.77 MHz RF voltage superimposed on the column electrode. The resultant energy of the H- ion was evaluated over one period of the RF to determine the maximum energy modulation received by an ion for a given RF peak voltage. Results from this simple model showed that for kilovolts of RF, about 75% of the RF amplitude was converted to energy modulation on the H- ion.

Detailed Particle Tracking Studies

To estimate the potential gain in WNR peak current with this approach, a detailed multiparticle beam dynamics simulation was performed using PARMILA. Starting at the end of the 80 kV column, a single gap cavity was used to simulate the net action of the new buncher. Nominal values for the transport magnetic lattice elements, RF bunchers and chopper settings were used in the simulation. PARMILA does not presently have either a DC column element to represent the 670 kV CW column or a chopper element capable of modulating the beam intensity. To get around these shortcomings, the simulation was divided into several pieces. PARMILA was used to track particles from the exit of the ion source to the entrance of the CW column. The particles were then "pushed" through the column, represented by a simple R-matrix obtained from a beam envelope model. Following the CW column, the particles were transported with

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PARMILA to the middle of the beam chopper. The distribution was "chopped" and the beam current was adjusted to reflect the total number of H- ions remaining in the beam (no space-charge compensation). The remaining distribution was transported with PARMILA to the beginning of the DTL and then to the end of DTL tank 2 (~40 MeV). The effectiveness of this new scheme was evaluated by comparing the number of particles accelerated to the end of tank 2 with and without the additional bunching.

The beam dynamics simulations showed that a net modulation of 1 keV applied through the column electrode, would result in a net increase of ~80% in the charge per WNR micropulse.

BUNCHER DESIGN AND IMPLEMENTATION

To test this concept a prototype buncher was developed and tested on the Ion Source Test Stand (ISTS) at LANSCE. It was implemented as a single resonant-frequency lumped-circuit operated with a capacitive load, i.e. the column gaps. The gap capacitance of the column electrode within the 80 kV column structure was modeled with the PANDIRA code [3] and was estimated to be ~222 pF. Using this value for the load, a prototype network was assembled to determine the proper sizes of the resonator inductance and supplemental capacitance, and to measure voltage gain. The overall prototype circuit is shown schematically in Figure 1.

The application of RF to a HVDC electrode presented several challenges. Since the adjacent electrodes in the DC column served as return paths for the RF currents, minimizing the impedance of these paths was important. The ground and HV leads were kept short by locating the network as close to the column as possible, while maintaining sufficient distance between the HV components and the grounded RF network enclosure. Spring-loaded stainless-steel contact pins used to bring HVDC through an acrylic jacket to the column electrodes were replaced with copper versions, which used small gold-plated bellows in place of the small spring-loaded contact. This reduced their RF impedance and voltage drop.

To reduce arc-down and corona problems the design incorporated DC blocking capacitors to minimize the additional number of components with HVDC across them. The capacitors (C_{block}) had to provide a low-impedance path for RF return currents, while blocking the -32 kV and -68 kV present on the column and extractor electrodes, respectively. Individual 3000 pF, 25 kV rated capacitors were assembled in stacks of two and three for the column and extractor, respectively. Corona rings were placed between the capacitors to suppress breakdown. A high-impedance voltage divider was used to establish an equal DC gradient across the capacitors in the extractor return path.

RF chokes (RFC) were used to minimize RF voltage present on the column HVDC power supply leads. These were fabricated on the test bench to be self-resonant just above our operating frequency, i.e. provide at least 5k Ohms. However, their actual performance changed a bit due to different boundary conditions at ISTS. The resonating inductor was tapped at the appropriate turn to provide a 50 Ohm feed point for the RF generator.

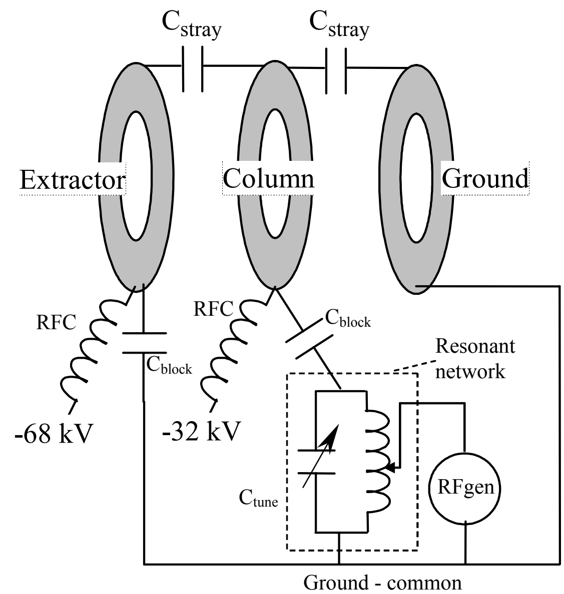

Figure 1: Schematic of prototype buncher circuit incorporated into HVDC column.

TESTING

The testing was performed in two phases. The first was rf only and followed the installation of the rf network. The second phase accomplished measurements with beam present, to quantify the bunching effectiveness.

Initial RF-only Measurements

To facilitate setup and debugging, the prototype buncher was first tested on the ISTS without an ion source present. With just the rf network attached to the column the resonant frequency was found to be several MHz below the target frequency. Efforts were made to raise the frequency, by reducing the inductance of various leads in the circuit, but the final operating frequency could only be raised to ~12.3 MHz. There was considerable inductance in the as-built mechanical layout of the ISTS, which effectively added parasitic inductance in series with each electrode and in the common ground return. These could not be removed without re-designing the structure, which was not an option for this experiment. The voltage gain of the circuit as measured between the column electrode and the RF input was ~10. Modifications to the RF resonator resulted in a somewhat higher frequency but at the expense of voltage gain. The decision was made to continue the testing with the higher voltage gain at 12.3 MHz, instead of the 16.77 MHz.

To limit the average power, all measurements were made with low-duty factor RF, i.e. 4 Hz x 400 µs. A pulsed signal generator driving a linear amplifier through a variable attenuator was used to produce up to 150 W of drive power. A bi-directional power coupler located between the amplifier and the resonator network was used to monitor both forward and reflected power. Under a no-load condition, ~1.5 kV_p RF was measured on the column electrode with 150 W. A small amount of RF, ~10% of column electrode signal was measured on the extractor electrode which indicated that it was not a "perfect" RF ground, due to stray inductance.

An ion source was installed and the column brought up to the nominal operating voltage of 80 kV. Operation with the column at 75 kV or higher resulted in occasional but persistent HV arcdowns. To limit any possible equipment damage from these arcdowns, the column operating voltage during these tests was limited to 70 kV.

Measurements with Beam

Following the installation and operation of an H- ion source on the ISTS, RF voltage synchronized with the beam pulses was applied to the column electrode to modulate the beam. The beam current signal provided by a simple Faraday cup at the end of the beam transport was used to measure the effect of the buncher. The beam and RF waveforms were recorded with a 500 MHz digital oscilloscope. Figure 2 shows a typical beam current pulse with the buncher enabled. By varying the beam energy and monitoring the phase of the modulation signal, the noise-like band following the beam pulse was determined to be RF pickup through the beam current measurement.

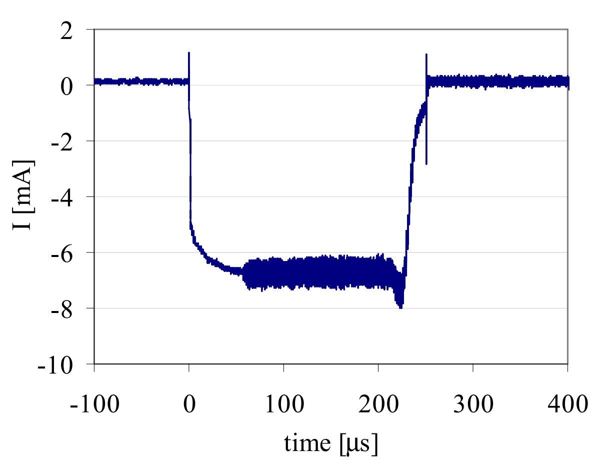

Figure 2: H- beam pulse (~7 mA) as measured with ISTS Faraday cup. RF bunching voltage applied ~60 µs after the start of beam pulse and remaining on for ~400 µs.

Beam-on data was collected at both 65 and 70 keV beam energies and included the magnitude of the beam-on and beam-off Faraday cup signals, and magnitude of the forward and reflected power waveforms. These were recorded at several drive power levels from ~18 to 150 W. Also, complete waveforms were recorded at a low and high power setting.

Also, the beam emittance measured with a slit and collector device showed very little difference between data taken with RF on and off.

ANALYSIS AND RESULTS

To determine the net beam modulation versus the net power supplied, i.e. forward minus reflected, a vector subtraction was performed between the measured beam-on and beam-off modulation signals. This approach was used to remove the RF pickup that was present on the Faraday cup signal whenever RF was on. A sine wave at the drive frequency was fitted to both beam-off and beam-on portions of the digitized Faraday cup signal to obtain the relative phase information. This was done with the low and high power waveforms and used to interpolate the relative phase of the signals for all the other data points where the magnitude of the signals was recorded. The net modulation was then corrected for the frequency response of the Faraday cup.

The analysis showed that with this scheme, ~140 W of net power resulted in about 22% modulation of the beam current at the location of the Faraday cup.

CONCLUSIONS

Tests on the prototype dome buncher demonstrated that RF voltage can be applied to the HVDC column electrode and result in bunched beam. However, the tests also revealed several issues that would need addressing before going further. The target frequency may be limited by the actual reactance of the column, from stray inductance and capacitance. The resonator approach was taken to reduce the amount of RF power required. Using a higher power RF generator, a non-resonant network would probably work as well, and be less susceptible to stray effects. Although the tests were successful, RF noise was observed on the ion source equipment racks floating at 80 kV, the Faraday cup and a Pearson current transformer located in the beam line. Better RF bypassing, shielding, and noise suppression would be essential for a production system. The DC blocking capacitors could be optimally designed to be series resonant at the target frequency, thus improving the RF grounding of the electrodes.

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